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Drs Danaei and Ezzati developed the study concept, and Dr Paciorek developed the statistical approach for the analysis of associations. Dr Ezzati wrote the first draft of the article, and Dr Paciorek wrote the first draft of the Statistical Methods. Drs Singh and Finucane and J. K. Lin analyzed data. Other members of the Writing and Global Analysis Group contributed to study design, analysis, and writing of article. The members of the Country Data Group analyzed health examination survey and epidemiological study data. Drs Danaei and Singh had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Dr Ezzati oversaw the research and is the study guarantor.

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Dr Paciorek holds stock in Pfizer. M. Cowan, Dr Stevens, and L. Riley are staff members of the World Health Organization. They alone are responsible for the views expressed in this publication, and they do not necessarily represent the decisions, policy, or views of the World Health Organization. The other authors report no conflicts.

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CLINICAL PERSPECTIVE

The diseases of affluence paradigm suggests that noncommunicable diseases are the modern scourges of the world and are hence more common in developed countries. But until now, little has been known about the associations of these risk factors with the macroeconomic characteristics of countries, and how the associations have changed over time. We examined this paradigm by using data from a global analysis of body mass index, systolic blood pressure (SBP), serum total cholesterol, and fasting plasma glucose. We found that in 1980, body mass index, SBP, and serum total cholesterol were in fact higher in wealthier countries. By 2008, there was either no relationship between SBP and national income (for men) or SBP was lower in wealthier countries (for women). This may be partly due to improved diagnosis and treatment in wealthier countries and perhaps subtle improvements in diet and lifestyle, for example, lower salt intake and year-round availability of fresh fruits and vegetables. The relationship between body mass index and national income in more recent years resembled an inverted U, in part, because overweight and obesity increased substantially in many middle-income countries. Unlike SBP and fasting plasma glucose, serum total cholesterol was associated with both income and Western diet throughout this period. We also found that fasting plasma glucose was positively correlated with body mass index but had little association with other national characteristics. If the observed trends continue, developed countries will continue to face an obese population with a high prevalence of diabetes mellitus and hypercholesterolemia, whereas developing countries will be confronted by a combination of obesity, hypertension, and diabetes mellitus. The diseases of affluence paradigm seems inadequate for explaining these nuances in the global epidemiology of cardiovascular risk factors and should be replaced with a more refined framework that better informs both policy and intervention.

Supplemental Material

Supplementary Text

The association of metabolic risk factors with income, urbanization, and western diet: statistical methods and considerations

All of our graphical and statistical analyses are based on a Bayesian multiple imputation approach. Specifically, the Bayesian statistical model for estimating risk factor levels borrowed information based on a hierarchy of countries within subregions and regions, across time and age groups, and using a small set of country-specific covariates. These covariates included the country-level characteristics considered in this paper's analyses, namely metrics of national income, urbanization, and western diet. This may appear to introduce circularity and potentially overestimate the association. Below, we provide the statistical justification for this approach and specify how we took into consideration the fact that the risk factor data were estimated using a Bayesian statistical model with covariates. In our explanation below, we conceptually divide our risk factor estimates into those that are essentially "known" based on good data for a given country-year and those that are imputed in the absence of such data; in reality there is a continuum of uncertainty.

First, we note that the covariates in the Bayesian model were chosen with the goal of best predicting country risk factor levels. The predicted risk factor levels used here are based on the posterior predictive distribution from the Bayesian hierarchical model, which conditions on all available information, both risk factor data and explanatory variables. As such, the posterior draws of country risk factor levels are a Bayesian multiple imputation. It is well known in the statistical literature that a correct multiple imputation procedure should condition on all available

information¹. Further, we note that the imputed country risk factor levels are based on the estimated relationship with covariates and the variability of country risk factor levels around the relationship, hence incorporating the variation around the estimated relationship. In other words, we draw from the posterior predictive distribution, which is the model's estimate of the distribution of the country risk factor levels, and therefore includes all of the appropriate sources of variation.

We can motivate the approach further by considering an example of why it would be incorrect to exclude the country-level characteristics of interest from the Bayesian hierarchical model. Suppose that we exclude a country covariate that is correlated with the risk factor of interest, and that none of the other covariates in the model are correlated with that characteristic. The result will be that our imputed values for missing country risk factor levels will not be correlated with the characteristic. When we produce figures such as Figures 1-3, those countries with data-driven, essentially-known risk factor levels would show a correlation with the characteristic but the imputed values would not, so the overall association would appear weaker than if we knew the true country risk factor levels. Now suppose that the characteristic of interest is not correlated with the risk factor of interest but that we include it in the Bayesian model. In the Bayesian model, we will estimate a near-zero coefficient based on the available country data, and the imputed values will be uncorrelated with the characteristic. Then in the subsequent analyses, neither the data-driven risk factor levels nor the imputed values will be correlated with the characteristic, and there will not be a circularity problem.

Given the uncertainty in the country-specific risk factor levels, including in relation to the covariates, our assessment of associations takes a missing data perspective and is based on a Bayesian multiple imputation approach^{1,2}. Specifically, we present the Loess fits, and the correlation and regression coefficients, in Figures 1-4 based on 500 posterior draws from the Bayesian model. Uncertainty intervals were calculated as the 2.5th to 97.5th percentiles of these 500 draws.

Supplementary Table

Table S1: Country data used in Figures 1-4 of the main paper. Data are from a systematic analysis of population-based data, by sex, for 199 countries and territories, as described in detail in previous publications³⁻⁶ and in the main paper.

Country	Percentage of GDP (2002-03)			Percentage of Domestic Demand			GDP (constant)			GDP (constant)			GDP (constant)			GDP (constant)		
	1980	2008	Change per decade	1980	2008	Change per decade	1980 (FtMn)	2008 (FtMn)	Change per decade (FtMn)	1980 (FtMn)	2008 (FtMn)	Change per decade (FtMn)	1980 (FtMn)	2008 (FtMn)	Change per decade (FtMn)	1980 (FtMn)	2008 (FtMn)	Change per decade (FtMn)
	1980	2008	per decade	1980	2008	per decade	1980 (FtMn)	2008 (FtMn)	Change per decade (FtMn)	1980 (FtMn)	2008 (FtMn)	Change per decade (FtMn)	1980 (FtMn)	2008 (FtMn)	Change per decade (FtMn)	1980 (FtMn)	2008 (FtMn)	Change per decade (FtMn)
Armenia	0.18	0.19	0.04	181	2027	2729	0.08	0.40	0.11	127,103,612.328	127,910,513.028	1,912	127,022,012.619	128,010,913.028	987	4,101,513.51	4,101,513.51	0.00
Aruba	0.54	0.74	0.07	4225	17662	4219	0.44	0.47	0.01	100,810,134.048	106,310,134.048	5,500	100,810,134.048	106,310,134.048	5,500	5,500,134.048	5,500,134.048	0.00
Australia	0.18	0.21	0.01	1389	4267	288	0.02	0.04	0.02	124,010,134.048	127,010,134.048	3,000	124,010,134.048	127,010,134.048	3,000	3,000,134.048	3,000,134.048	0.00
Austria	0.07	0.12	0.02	1798	16107	1793	0.17	0.14	-0.04	124,010,134.048	127,010,134.048	3,000	124,010,134.048	127,010,134.048	3,000	3,000,134.048	3,000,134.048	0.00
Azerbaijan	0.07	0.04	-0.04	1950	3259	1309	0.70	0.29	-0.41	100,000,000,000	100,000,000,000	0.00	100,000,000,000	100,000,000,000	0.00	100,000,000,000	100,000,000,000	0.00
Bahrain	0.38	0.51	0.05	553	5910	279	0.45	0.47	0.02	127,010,134.048	131,010,134.048	4,000	127,010,134.048	131,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Bangladesh	0.26	0.23	-0.01	1039	3562	253	0.40	0.49	0.09	121,010,134.048	125,010,134.048	4,000	121,010,134.048	125,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Barbados	1.00	1.00	0.00	2096	6106	4010	0.52	0.49	-0.04	141,020,134.048	127,020,134.048	-14,000	141,020,134.048	127,020,134.048	-14,000	141,020,134.048	127,020,134.048	-14,000
Belarus	0.83	0.80	-0.07	1839	10303	475	0.44	0.44	0.00	105,010,134.048	106,010,134.048	1,000	105,010,134.048	106,010,134.048	1,000	1,000,134.048	1,000,134.048	0.00
Belgium	0.23	0.21	-0.02	2005	2144	139	0.14	0.14	0.00	100,010,134.048	102,010,134.048	2,000	100,010,134.048	102,010,134.048	2,000	2,000,134.048	2,000,134.048	0.00
Belize	0.21	0.21	0.00	1046	5103	444	0.34	0.44	0.11	101,010,134.048	104,010,134.048	3,000	101,010,134.048	104,010,134.048	3,000	3,000,134.048	3,000,134.048	0.00
Benin	0.21	0.18	-0.03	1046	2144	139	0.14	0.14	0.00	100,010,134.048	102,010,134.048	2,000	100,010,134.048	102,010,134.048	2,000	2,000,134.048	2,000,134.048	0.00
Bhutan	0.33	0.25	-0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Bolivia	0.15	0.15	0.00	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Bosnia and Herzegovina	0.20	0.20	0.00	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Botswana	0.48	0.75	0.09	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Brazil	0.63	0.67	0.04	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Bulgaria	0.51	0.48	-0.03	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Burkina Faso	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Burundi	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Cambodia	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Cameroon	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Canada	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Chad	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Chile	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
China	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Columbia	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Costa Rica	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Cote d'Ivoire	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Croatia	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Cuba	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Cyprus	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Czechia	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Dominican Republic	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Dominican Republic	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Dominican Republic	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Dominican Republic	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Dominican Republic	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Dominican Republic	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Dominican Republic	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Dominican Republic	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Dominican Republic	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Dominican Republic	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Dominican Republic	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Dominican Republic	0.20	0.28	0.08	1046	1411	365	0.40	0.47	0.07	100,010,134.048	104,010,134.048	4,000	100,010,134.048	104,010,134.048	4,000	4,000,134.048	4,000,134.048	0.00
Dominican Republic	0.20	0.28	0.08	1046	1411	365	0.40											

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